

Macadamia:

Hawaii's Dessert Nut

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Cover photograph: Two of the heaviest producing macadamia trees in the world, 25-year-old trees of the 'Keauhou' variety at the Kona Research Station in Hawaii.

**MACADAMIA:
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The macadamia nut, native to the coastal rain forest areas of southern Queensland and northern New South Wales in Australia, is considered to be the world's finest dessert nut. It belongs to the Proteaceae family and is unique in that it is the only native Australian plant to attain the status of a commercial food crop.

Macadamia seeds were first imported into Hawaii in 1882 by William Purvis, and macadamias have since become the most important tree crop in this state. More than 90 percent of the world's production of macadamia nuts is grown on Hawaii, the southernmost island in the state. Small acreages are also grown on Maui and Kauai. Orchard plantings have been made in Australia, South Africa, and California, and more recently in Malawi, Kenya, Rhodesia, Guatemala, Costa Rica, and Brasil. Many of these orchards are still in developmental or trial stages. Most macadamia plantings in these countries have been made with Hawaiian cultivars. These cultivars were primarily selected for Hawaiian growing conditions and may not perform well elsewhere. In Hawaii, where improved clonal varieties have been selected and grown for about 35 years, macadamia nuts have achieved major success as a commercial crop. Macadamias are presently in good demand in Hawaii, the mainland U.S., and the world market. Prices of in-shell nuts and processed kernels have remained relatively high because demand often exceeds supply. Currently the U.S. grows, processes, and consumes most of the macadamia nuts produced in the world. However, there appears to be good potential for marketing macadamia nuts in other countries.

Description and Botany

The two species that produce edible kernels are *Macadamia integrifolia* and *Macadamia tetraphylla*. Both species are attractive, medium-

sized, evergreen trees; with age they often attain a height of 60 feet or more, and a spread of about 40 feet. They have shiny, green, holly-like foliage, and grafted trees of selected varieties make attractive, shapely specimens well worth growing as combination ornamental, shade, and nut trees.

M. integrifolia, the only commercially important species, commonly known as "smooth-shell" macadamia, has proven suitable for large-scale processing as a high-quality dessert nut. The fruit is a follicle with a husk that opens along one suture enclosing a single seed, rarely double, with a very hard seed coat. The seed coat is commonly known as the shell. The edible part, or kernel, is the creamy white embryo containing up to 80 percent oil and about 4 percent sugar when dry. It is enclosed by a hard, round shell ranging from about 0.8 inch to 1.1 inches in diameter, which is in turn enclosed within a dull green pericarp usually referred to as the husk. The shiny, oblong leaves are 5 to 10 inches long and characteristically borne in whorls of 3 at a node. Margins of leaves of older trees are usually smooth, but those of young seedlings are often spiny. New growth varies in color from light green to bronze. The small, perfect, cream-colored flowers are borne in axillary racemes 6 to 12 inches long consisting of several hundred flowers. Although there are a large number of flowers in each raceme, usually not more than about 10 nuts set and mature.

The "rough-shell" species, *M. tetraphylla*, produces slightly spindle-shaped nuts that usually have rough, pebbled surfaces. The coarse, leathery leaves, up to 20 inches long, borne in whorls of 4, are sessile with thorny, toothed leaf margins. New growth may be either reddish, purple, or pale green. The flowers are usually pink (rarely cream colored), and borne in racemes 8 to 15 inches long. The kernels are usually darker colored than the other species, and often have a grayish upper half. They are much more variable in quality than smooth-shell kernels, ranging from about 67 to 75 percent oil and 6 to 8 percent sugar. This high sugar content make the kernels palatable and pleasant for eating raw, but their high sugar content and marginal oil content make them characteristically variable in color, texture, and flavor when cooked. Varieties suitable for commercial processing into a roasted, vacuum-packed product have not yet been found. Rough-shell macadamia trees have been planted both as ornamental or shade trees, and for their edible kernels. *M. tetraphylla* seedlings are sometimes used as seedling rootstocks for smooth-shell varieties, although scion



Figure 1. Flower racemes and fruit cluster of smooth-shell macadamia, *M. integrifolia*.

overgrowth is not uncommon and is considered undesirable when it occurs.

Many trees that are hybrids between the two species have been found, but to date no important clonal selections of hybrid origin have been discovered. Kernel quality of these hybrids usually resembles the rough-shell species, which, as noted, is inferior for processing.

Varieties

About 50 macadamia cultivars have been described from Australia, California, South Africa, and Hawaii. The first 5 varieties named in Hawaii were released in 1948; and a total of 13 clones have now been selected, tested, and named by University of Hawaii horticulturists. Of these 13 varieties, 7 are presently being recommended for orchard

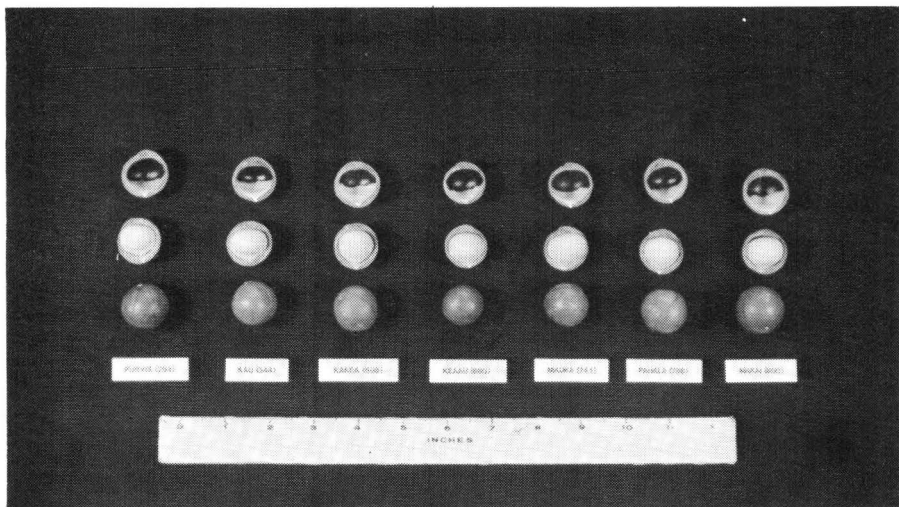


Figure 2. Shell, kernel, and nut characteristics of recommended commercial macadamia varieties. Left to right: 'Purvis' (294), 'Kau' (344), 'Kakea' (508), 'Keaau' (660), 'Mauka' (741), 'Pahala' (788), and 'Makai' (800).

planting in the state. These are 'Kau' (344), 'Kakea' (508), 'Keaau' (660), 'Mauka' (741), 'Makai' (800), 'Purvis' (294), and 'Pahala' (788). Original selection numbers of these varieties are listed in parentheses since many growers and nurserymen still prefer to use the numbers instead of names. These 7 varieties, all developed by University of Hawaii plant breeders, are presently recommended for planting in commercial orchards in Hawaii. 'Keauhou' and 'Ikaika', although prominent in early commercial plantings made prior to 1965, are no longer recommended for new plantings. This is because newer varieties now recommended have given higher yields of grade 1 kernels in long-term, replicated yield tests in Kona and Waiakea experiment stations. Varieties presently recommended are:

1. 'Purvis' (294)

'Purvis' was first selected in 1936. It was named, in 1981, in honor of the late William Purvis, who introduced and planted the first seed nuts of *M. integrifolia* in Hawaii in 1882. It is interesting to note that one of the original trees from this introduction still survives and is producing nuts at Kukuihaele, on the Island of Hawaii. 'Purvis' trees have consistently produced crops averaging higher in grade 1 kernels than the first 5 cultivars named in 1948, with the exception of 'Kakea'. 'Purvis' produces large kernels of exceptionally good quality and flavor.

2. 'Kau' (344)

'Kau' was first selected in 1935, but not officially named until 1971. 'Kau' resembles 'Keauhou' in nut characteristics and productivity, but has better quality kernels than 'Keauhou' in most locations. The tree form of 'Kau' is more upright than 'Keauhou', and it is considered hardier and more wind resistant. 'Kau' is a productive variety that appears to be well adapted to elevations from 300 to about 2000 feet.

3. 'Kakea' (508)

'Kakea' is an excellent commercial cultivar, first selected in 1936 and named in 1948. It has performed exceptionally well in long-term yield trials at the Poamoho, Waiakea, Haleakala, and Kona experiment stations. It is reasonably hardy, producing kernels of excellent quality, and has been consistently productive and long-lived at all test locations. Its growth habit is more upright than 'Keauhou', and because of this, young trees may need to be topped. It is also considered somewhat more difficult to graft than most other varieties. 'Kakea' remains one of the best and most reliable varieties for commercial planting in Hawaii and is the best of the 5 varieties named by Dr. W. B. Storey in 1948.

4. 'Keaau' (660)

'Keaau' was selected in 1948 and named in 1966. It has an upright growth habit, permitting somewhat closer planting than varieties with more spreading trees. 'Keaau' has outstanding nut and kernel characteristics, with 42 to 46 percent kernel; more than 95 percent of its kernels are grade 1. 'Keaau' trees have performed well in most areas where this variety has been tested.

5. 'Mauka' (741)

'Mauka' is a relatively new cultivar, selected in 1957 and named in 1977. It has been named 'Mauka', which means "toward the mountain," because it has performed well in test plantings at elevations from 1800 to about 2000 feet, where most other cultivars are marginal. It is a hardy tree producing nuts similar in size and percentage of No. 1 kernels to those of 'Kau', but with a higher kernel percentage of up to 43 percent kernel compared to about 38 percent for 'Kau'. 'Mauka' has about 13 percent greater recovery of No. 1 kernels from a given weight of in-shell nuts than 'Kau'.

6. 'Pahala' (788)

One of the newest varieties of macadamia, 'Pahala' was first selected in 1963 and named in 1981. The growth habit of the tree is narrow

and upright so that 'Pahala' trees require somewhat less space in the orchard than other varieties with larger, wider trees. Up to 120 percent more 'Pahala' trees per acre can be planted than with varieties having larger, more spreading trees. Rate of recovery of grade 1 kernels from dry nuts of 'Pahala' was about 41.1 percent, which is approximately 50 percent higher than 'Keauhou'. While overall yield capacity of 'Pahala' still needs further testing, nut characteristics and kernel quality have been adequately tested and found to be as good as, or better than, any other commercial variety currently recommended.

7. 'Makai' (800)

This promising high-quality cultivar was first selected in 1967 and named in 1977. It has been given the name 'Makai', a Hawaiian word meaning "toward the sea." 'Makai' has shown better adaptation to lower elevations than other recent selections and older cultivars. 'Makai' is a seedling of 'Keauhou', which it most resembles in form, nut characteristics, and yield potential. The kernel quality and percentage of grade 1 kernels of 'Makai' are, however, significantly better than those of 'Keauhou'.

All of the 7 recommended varieties have given good yields of excellent quality nuts in favorable orchard sites ranging from about 300 to 1800 feet elevation; however, 'Mauka' and 'Kau' appear somewhat better adapted to elevations above 1800 feet than other varieties.

Yields and Spacing

With good care, in suitable areas of Hawaii, improved cultivars usually begin producing appreciable crops by 7 years after planting, and attain full production in 10 to 12 years.

Yields from well-managed, mature, clonal orchards in Hawaii have ranged from 1.0 to 4.5 tons of in-shell nuts per acre, depending on location and variety. Macadamia trees have not responded favorably to close planting, and the spacing in the heaviest producing orchard on record was 34 by 34 feet. In the past, most orchards in the state were spaced from 20 to 30 feet between adjacent trees; but, unfortunately, spacings of less than 30 feet often result in excessive crowding, which generally occurs by the ninth or tenth year. Crowding adversely affects yields so that thinning or heavy pruning becomes necessary. With standard-sized trees, spacings of about 30 to 35 feet between rows and 16 to 20 feet between trees in the row are considered reasonable, depending on tree form and growth rate of the trees.



Figure 3. An example of scion overgrowth: smooth-shell variety grafted on rough-shell rootstock.

Spacing of up to 20 feet between trees within the row can be advantageous because it permits removal of alternate trees in the row when this becomes necessary due to crowding as the trees increase in size with age.

Propagation

Vigorous, well-grown seedlings of both species have been used successfully as rootstocks in commercial orchards. Rough-shell seedlings are sometimes preferred by nurserymen because they germinate uniformly, grow faster and more uniformly in the nursery, and are considered somewhat easier to graft and transplant. There is, however, a possible problem whenever rough-shell seedlings are used as rootstocks for smooth-shell varieties. The trunk of smooth-shell varieties sometimes grows faster and increases in diameter more rapidly than the rough-shell rootstock. When this occurs, the trunk just above the graft union becomes larger and thicker than the rootstock section below the graft union. This problem, known as scion overgrowth, is considered undesirable in orchard trees and should be avoided. Fortunately, it rarely occurs when smooth-shell varieties are grafted on smooth-shell seedlings. Most of the trees in producing orchards in

Hawaii are, however, grafted on smooth-shell rootstocks because there is no adequate reliable source of proven rough-shell seed available in Hawaii.

Macadamias are not considered difficult to graft, but actual experience with macadamias is usually essential for success because the wood is exceptionally hard and brittle. Scion-wood girdled at least 5 weeks in advance is usually necessary for successful grafting. Vigorous seedling rootstocks $\frac{1}{4}$ to $\frac{3}{4}$ inch in diameter, which are usually about a year old, are grafted by various methods, the side-wedge and the top-splice grafts being preferred. Bark or veneer grafts can be used in topworking larger trees up to about 6 inches in diameter. Topworking larger trees, a foot or more in diameter, has not given as good results as with smaller trees and is therefore not recommended.

Climatic Adaptation

Important factors to be considered in deciding on suitable locations for new macadamia orchards are soil, natural wind protection, elevation, rainfall, and accessibility for harvesting and cultural operations.

Macadamias have proven best adapted to mild, frost-free, subtropical climates with at least 60 inches of annual rainfall fairly well distributed throughout the year. Although macadamia trees tolerate and survive mild frosts and drought conditions, yield and quality are adversely affected. In Hawaii, the best conditions for growing macadamias are found between 700- and 1800-foot elevations, although a few moderately successful plantings have been made lower than this. Macadamia trees are susceptible to wind damage and do best with good, natural wind protection or adequate planted windbreaks. When there is less than 60 inches of well-distributed annual rainfall, supplementary irrigation is beneficial since moisture stress can cause reduction in yield and quality of nuts. There are also indications that temperatures over 90°F reduce production and growth, but fortunately these temperatures seldom occur where macadamias are grown in Hawaii.

Soils and Fertilization

Macadamia can be grown successfully on a variety of Hawaiian soils ranging from loose a'a lava soil to well-drained Latosols.

Fertilization is necessary for good growth and production. Slow-release fertilizers with a 2-4-1 or 1-1-1 ratio (depending on soil and location) of nitrogen-phosphorus-potassium have given good

results. Soil tests and leaf analyses of nutrient elements should be used as a guide for the orchard fertilizer program. Leaves sampled from the second whorl below the developing tip at the beginning of vegetative flush (around March in Hawaii) should contain the following amounts of the major elements (by percentage of dry weight):

N (Nitrogen) = 1.5–1.6%

P (Phosphorus) = 0.08–0.10%

K (Potassium) = 0.45–0.65%

In soils having low phosphorus-fixing capacity (e.g., unweathered lava), fertilization with excessive phosphorus can lead to immobility of iron in the plant, and the appearance of iron-deficiency symptoms (chlorosis in leaves). A phosphorus level of 0.12 percent in the leaves can be excessive.

Fertilizer applications should be made 3 to 4 times per year, with the amount of fertilizer increasing at the rate of the square of the trunk circumference until the trees close in. Leaf analysis should be used as a guide to the amount and ratio of fertilizers used. The most common microelement and sulfur deficiencies can be corrected by soil applications of appropriate materials (except in the case of iron, which is applied as foliar spray). Liming is beneficial to tree growth and yields on soils with pH values less than 5.5.

Diseases and Pests

Macadamias in Hawaii are comparatively free from serious diseases and pests. Several problems sometimes occur, however, so that control measures should be instituted as necessary. Stick-tight nuts (anthracnose) are said to be caused by *Colletotrichum* spp., which darken and kill the husks of developing nuts, causing them to hang on the tree after the crop has matured. Stick-tight nuts are a serious problem because they are generally of inferior quality and difficult and costly to separate from good nuts. Anthracnose damage most commonly occurs in wet, humid areas, but can be controlled by planting resistant varieties. The 'Keauhou' variety is immune to anthracnose, and most other commercial varieties have moderately good resistance. Flower racemes are sometimes subject to fungus attack, which is thought to reduce the crop. Fungi involved are *Botrytis* spp. and *Phytophthora* spp. This type of damage usually occurs during periods of high humidity. Some reduction in fruit set may occur, but no spray program or other control measure is in general use.

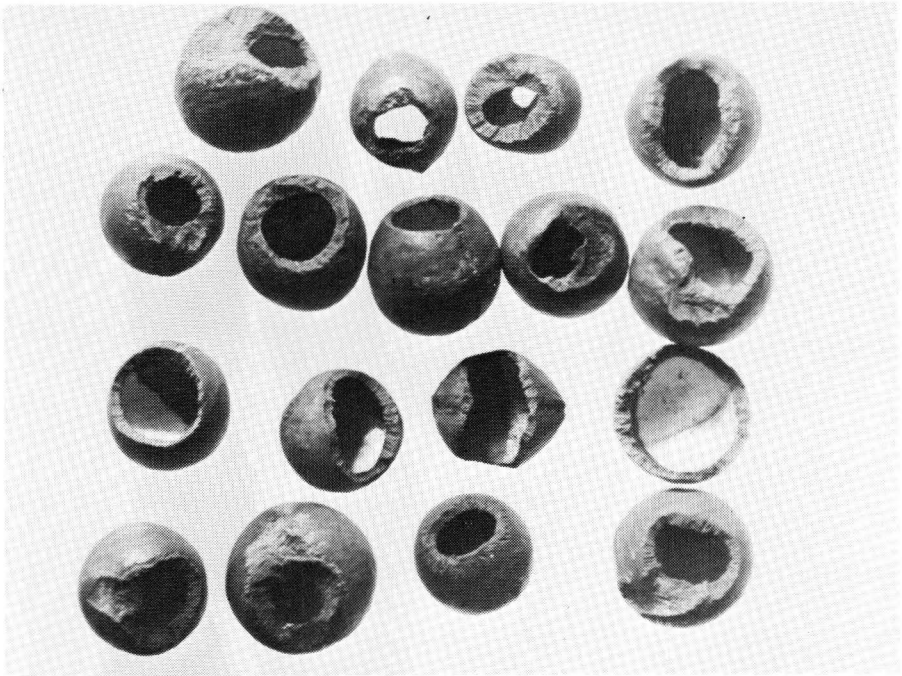


Figure 4. Macadamia nuts with kernels eaten by rats.

Phytophthora cinnamomi, which also causes avocado root-rot, occasionally attacks the trunk and main branches of macadamia trees, but does not seem to affect the roots. Affected trees are weakened and sometimes girdled and killed, but the disease is much more frequent on seedling trees than in grafted orchards. This disease is so infrequent in commercial orchards that, to date, control methods have not seemed warranted.

Rats, wild pigs, and nut borers that feed on macadamia nuts sometimes cause considerable crop loss. Rats feed on the kernels of both mature and immature nuts. They can be kept under control with a well-planned poison bait program. Wild pigs often invade macadamia orchards to feed on mature nuts that have fallen to the ground. When numerous enough to be a problem, wild pigs have been successfully controlled by hunting and trapping them in and around the

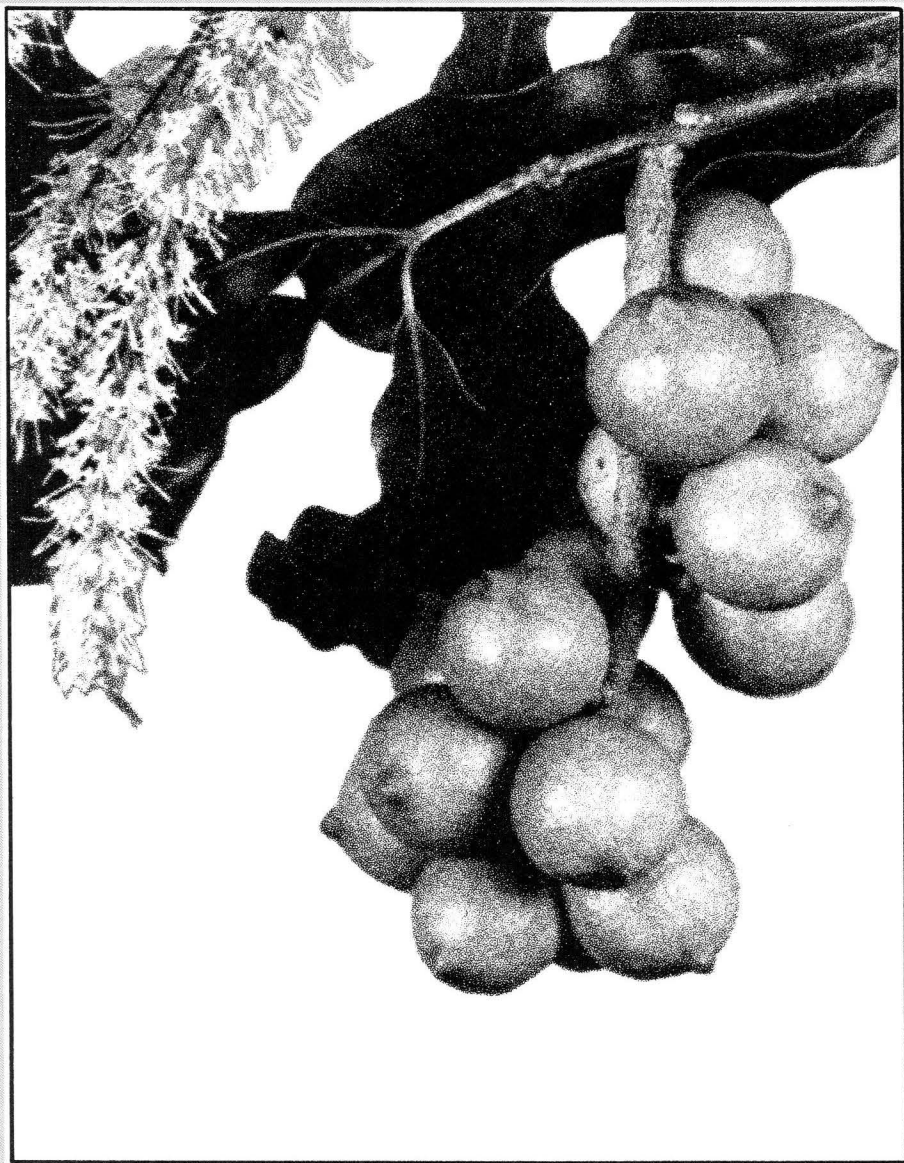
orchard. Two nut borers, *Cryptophlebia illepidia* (koa seedworm) and *C. ombrodelta* (lychee fruit moth), cause some damage by boring into the immature nut and causing early drop. Sometimes they bore through the shell and feed on the kernel inside. Considerable damage from nut borers may occur in the first harvest of early maturing nuts, but losses to the main crop are seldom serious. Up to now, macadamia growers have not found it necessary to use control measures against nut borers.

Leaves and husks of developing nuts often become heavily infested with thrips and mites. Effects on quality and production of nuts have not been established, however, and control programs are not generally necessary in commercial orchards. Young leaves on new growth flushes, flower buds, and flowers may become infested with the black citrus aphid, *Toxoptera aurantii*, and the broad mite, *Polyphagotarsonemus latus*. These pests can be controlled by spray applications of insecticides and miticides that have been cleared for use on macadamia. The southern green stink bug, *Nezara viridula*, feeds on developing nuts, causing unsightly spots on the kernels of affected nuts. Introduced parasites have reduced stink bug populations, and since macadamias are not a preferred host plant of stink bug, the amount of damage that occurs is generally not a cause of great concern.

Harvesting and Processing

The main harvest period for macadamia nuts in Hawaii extends from about August through January. October and November are peak months, but it is common for some nuts to mature every month of the year. 'Keaau', 'Kau', and 'Mauka' have comparatively short harvest periods, maturing most of their crop in September, October, November, and the first part of December. Macadamia nuts fall to the ground when mature and should always be gathered before they begin to mold, germinate, or become rancid. During rainy weather this should be every 2 to 3 weeks, but if the weather is dry, collection intervals can be extended to once a month. Husking should be done within 24 hours after harvesting to prevent development of off-flavors. The husked nuts should be dried in wire-bottomed trays under shade for about 2 weeks or in a forced-air dryer for 3 days at 100° F. The drying process is completed by drying the nuts in bins at 125° F to bring them down to approximately 1½ percent kernel moisture. Dried kernels are processed by roasting them in refined cooking oil for 12 to 15 minutes at 275° F, or dry roasting in a forced-air oven.

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